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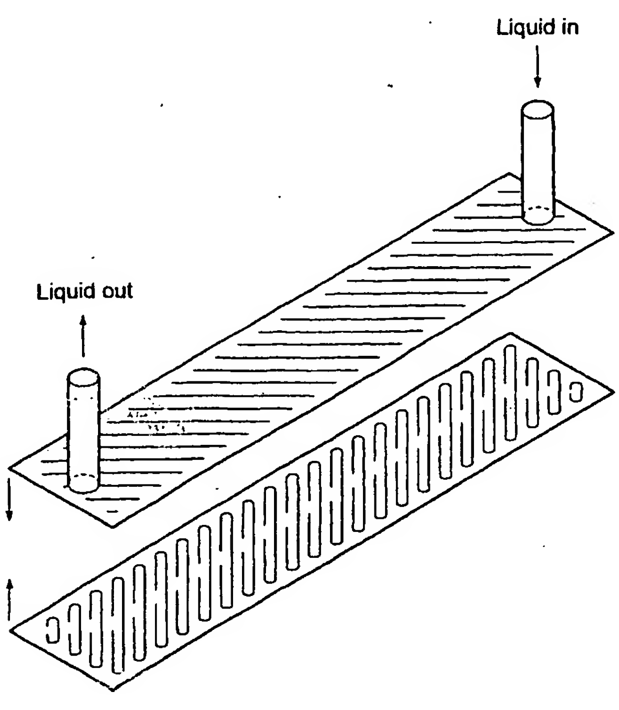
(54) Title: NOVEL POROUS ELEMENT AND USE THEREOF



(57) Abstract: A porous bilayer element arranged such as to form respective flow paths for first and second gaseous or liquid fluids, which fluids may be the same or different, wherein the bilayer is adapted for turbulent flow of at least one of the first and second fluids.

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NOVEL POROUS ELEMENT AND USE THEREOF

The present invention relates to a novel porous element adapted for contact by fluid(s), apparatus comprising such an element, the preparation and uses thereof, in particular to a porous membrane or filter bilayer element having a favourable size and configuration of surface area, processes for the preparation thereof and uses thereof in mass transfer or separation of fluid (mixtures).

In recent years polymers have become available with attractive mechanical properties and chemical and fouling resistance, whereby there is an emerging opportunity for these polymers to displace metals in the construction of apparatus which operate in fluid contact.

PCT/GB96/02189 discloses the use of these materials for heat exchange, in view of their high temperature stability. The film is corrugated so that adjacent film layers may be held apart by the corrugations which cross at approximately 90°. Where heat is being transferred from fluid A to fluid B, these fluids flow alternately between layers of corrugated film.

However, due to the limited flue gas pressure drop available, a heat exchanger based upon a polymer film matrix, with its narrow flow channels, must involve a gas flow path length of only 10cm or so. PCT/GB96/02189 is concerned with a novel design for achieving that requirement economically. While the design is particularly relevant to flue gas cooling with liquids, it also has significance for any gas-liquid heat transfer operation where the gas pressure drop is restricted.

In technologies involving mass transfer, separation, filtration and the like of fluids it is common to employ a flat membrane separating fluid streams in cross flow. The flat membrane may comprise the partition between fluid flows or may be a layer applying to a porous partition. For example, WO 93/11087 discloses a ceramic cross flow unit for fluids filtration comprising a porous membrane layer at the channel

surfaces, for example a sintered ceramic, an organic polymer, a molecular sieve, a gel filtration layer or a microporous gaseous diffusion area.

EP 0 532 237 discloses a filter assembly of two disk shaped filter elements stacked within a housing. each element having a porous filter membrane covering both of its sides and being separated and supported by a spacer. The apparatus is adapted for filtering viscous polymers, for example.

In GB 2 236 693 is disclosed a flat self-supporting filtration membrane for cross flow, comprised in a unit of two membranes with peripheral seals holding the plates apart to form a flow channel. Pore size is from 0.1 to 10μm and may be included in an independent sheet of polymer which is bonded to the face of the ceramic membrane which has larger pores. The unit eliminates the need for separate support plates and gives a more compact filter unit.

In DE 3125222 is disclosed a membrane assembly for separating fluid mixtures comprising two semi permeable membranes with a porous support therebetween.

DE 3028398 discloses a filtration unit comprising permeable membranes and designed to provide constant flow resistance over the whole membrane area to minimise dead zone formation. DE 2530046 discloses a flexible membrane support for liquid separations and having an extended shell which is capable of a forming at least one loop on itself whereby the wound or coiled membrane provides a saving in space.

Accordingly it will be apparent that the literature relating to membrane separation of filtration units is concerned predominantly with stabilising fluid flow, providing spacers or stackers between adjacent membranes without flow disruption and the like. In particular membranes may be configured to provide fluid flow channels to ensure flow uniformity, or may be spaced with porous spaces through which fluid may flow. Moreover membranes may be configured in a manner so as to save space.

One object in cross flow filtration is to maximise flux of apparatus. Flux is defined as the rate of flow of mass, volume, or energy per unit cross section normal to the direction of flow, and is typically a measure of the intensity of transfer of mass or energy between cross flowing fluids and therefore a measure of the maximum filtration efficiency.

It has therefore been thought that flux may be enhanced by deforming the flow and by varying the nature and porosity of membranes.

Enhancement of efficiency of mass transfer and separation in fluid flow is a constant aim and embodiments of the present invention therefore seek to provide a novel porous element such as a membrane or filter adapted for flux enhancement in cross flow.

We have now surprisingly found that a particular configuration of membrane or filter element serves to provide significant flux enhancement in an admirable manner.

According to a first aspect of the present invention, there is provided at least one porous bilayer element arranged such as to form respective flow paths for first and second gaseous or liquid fluids, which fluids may be the same or different, wherein the bilayer is adapted for turbulent flow of at least one of the first and second fluids.

Preferably the element is porous to at least one component of the first and second fluids, which component may comprise or be contained within the fluid. Preferably the element is a membrane or filter element, hereinafter a membrane. Preferably the ratio of the surface area of membrane adapted to contact both fluids to the total matrix volume is in excess of $700m^2/m^3$, preferably in excess of $1000m^2/m^3$, for example being of the order of $1500m^2/m^3$.

The bilayer membrane is suitably configured to provide the ratio of surface area to matrix volume as hereinbefore defined. Preferably each membrane of a bilayer provides fluid flow channels for one of the first and second fluids and provides turbulence generating means for the other of the other of the first and second fluids. It is a particular advantage that the flow channels for the at least one fluid may provide on their reverse side the turbulence generating means for the at least other fluids. More preferably the bilayer membrane is corrugated and comprises two corrugated membranes disposed to provide cross corrugation.

It is a particular advantage that the bilayer membrane of the invention serves also to provide spacing means for securing membranes at a desired separation to provide respective fluid flow regions, by means of interaction of respective fluid flow channels and turbulence generating means. In particular the spacing achieved with cross corrugated bilayer membranes is particularly advantageous. It is a particular advantage that the ratio of the surface area to total matrix volume of the element of the invention may be obtained as a result of the configuration thereof, with associated manufacturing efficiency and with acceptable pressure drop.

By means of the bilayer of the present invention it is possible to provide a total surface area to path length of first and second fluids which is economically attractive in terms of degree of mixing separation and yet wherein the bilayer is such as to ensure acceptable pressure drop, thereby avoiding leakage and failure thereof. The bilayer is ideally suited for use in filtration and separation and mass transfer applications.

Reference herein to matrix volume is to the total volume defined by the bilayer, including the volume defined by the external surface thereof, which is adapted to be contacted by the first or second fluids, but excluding supply and effluent manifolds volume and headspace, for example such as provided by a mandrel about which the bilayer element may be fitted or wound and possibly held in place by a restraining band.

The device can be used in separations of solid and liquid particles from liquids and gases, for separation of dissolved solids, organic compounds, salts, ions etc. from liquid, separation of gases and vapours from liquid, for the transfer of dissolved constituents from one phase to another phase, e.g. in extraction, gas absorption, gas stripping. The device can be used to contact two phases to facilitate reaction therebetween. The device can be applied to the processes of microfiltration, ultrafiltration, nanofiltration, reverse osmosis, gas permeation, vapour permeation, membrane distillation, dialysis, electrodialysis, membrane ion exchange, membrane reactors, fuel cells and any system where membranes or porous filters benefit the separation or mass transfer process.

Gaseous and liquid fluids for mixing and separation purposes may be selected from any fluids conventionally employed for such purpose, in particular fluids to be filtered such as flue gases, food products, water, biological fluids, processing and furnace fluids or the like, in particular for the recovery of solid contaminants from fluids, such as washing effluents or other domestic or industrial effluents.

Suitably in the bilayer of the invention the flow path length of the first fluid is less than the flow path length of the second fluid and may even be made very short. This is a particular advantage of the instance that the fluids are not the same, whereby one fluid is more susceptible to high pressure drop formation, for example if it is gaseous.

Membranes may be microporous with a pore size in the range 0.01 to 500μm, preferably 0.01 to 250μm, most preferably 0.02 to 50μm, with 5-95% porosity nominally. Smaller pores of the size of molecules as in reverse osmosis membranes can be used. Materials may be constituted as non-porous.

Preferably a bilayer as hereinbefore defined comprises two corrugated polymer films arranged at an angle of cross corrugation of 25° to 90°, more preferably arranged at an angle of 60° to 90° in the event that the fluid flow paths are comprised substantially

in a straight plane, or of 25° to 60° in the event that the flow paths are comprised in a substantially curved or angled plane.

The bilayer may be made from the same or from different membranes. Materials with different characteristics, for example, of porosity or separation ability may be used e.g. in ion-exchange membrane separations (electrodialysis) and in processes where a reaction may occur e.g. in fuel cells and membrane reactions.

Membranes may comprise any suitable membrane material and are preferably made of a single or composite material selected from porous metals, ceramics, polymers, plastics, glass and the like, for example a coated material with suitable separation characteristics, a combination of polymer and inorganic membrane, a reinforced (carbon or glass) polymer and the like.

Suitable materials are commercially available and area described in the Handbook of Industrial Membranes, Keith Scott, ISBN 1 85617 233 3, Elsevier Scientific Publishing Limited.

Polymers exhibiting suitable properties are selected for example from PTFE, polyvinyl such as PVDF, polyaromatics such as polyether sulphones and ketones (PES and PEEK) and are of particular advantage, having suitable working temperatures, flexibility, mechanical strength and resilience. Other polymers such as HDPE, UHDPE, polypropylene and the like may be useful in specialist applications, such as immobilising catalysts. A particularly advantageous membrane material is Gore-Tex® PTFE, which has been found to be stable, very porous and non-tortuous. Preferably membranes are of thickness of the order of micrometres, for example 100-500μm, whereby flux rate is enhanced. It is a particular advantage that modest tension may be applied to membranes during construction into spiral and like configurations, whereby the resulting element is mechanically robust and adapted to resist forces such as generated by turbulence and the like. Polymer membranes may include suitable fibre reinforcement and the like as is known in the art, preferably

carbon or glass fibre reinforcement. Polymer membranes may be obtained pre-corrugated or may be corrugated in the process for the preparation of the bilayer using known techniques.

Preferably membranes are constructed of thermoplastic polymers; for example cellulose acetate/nitrate is not preferred since the resilience to corrugation is low.

Corrugated polymer films may have any desired profile adapted to create and regulate a desired flow path therebetween, and preferably may have a sinusoidal, saw tooth, square-sinusoidal profile or the like. Corrugation wavelength is conveniently measured in terms of peak to peak separation, and may be of any suitable value adapted for the desired separation or mass transfer duty and acceptable pressure drop, and may also be adapted to allow for passage of any solid contaminants without blocking in the event that filtration is ineffective or undesirable. Preferably the wavelength is of the order of up to 1cm, more preferably in the range 1 to 6mm, such as for example 2 to 4mm. Choice of corrugation profile may conveniently be made with reference to the mixing and distribution characteristics required for a given application. Individual layers of bilayers may be different in corrugation shape and material.

Angle of cross-corrugation may suitably be selected according to turbulence characteristics required for a given application. Moreover a large cross-corrugation angle will provide less pressure drop, but less bilayer flexibility to desired deformation.

In a particular advantage of the present invention, a bilayer may be employed which occupies a small total matrix volume as hereinbefore defined, and yet which provides similar or superior fluid contacting with respect to conventional apparatus.

A bilayer as hereinbefore defined may be elongate and formed into a geometric form whereof the longest dimension is less than the path length of the second fluid.

Suitably a geometric form is stacked, layered or otherwise repeating or extending in three dimensions, whereby each of one or more continuous second fluid flow paths encloses a plurality of first fluid flow paths. This is particularly advantageous when the number of discrete first fluid paths is greater than that which would be provided by a straight planar 2 dimensional bilayer having the same longest dimension.

The geometric form of a bilayer may be selected according to the desired application, in particular with reference to the physical and mechanical constraints and volume to be accommodated.

It will be appreciated that a single bilayer is adapted for the passage of a first fluid and a second fluid in cross directions, one of which is contained within the bilayer and thereby isolated from the other which contacts the outer surface of the bilayer, along the external corrugations thereof. Suitably therefore a bilayer is sealed in known manner at its periphery to contain the second fluid in suitable manner.

In a preferred embodiment a bilayer is formed into an open, closed or concentric spiral plane which is curved or angled, such as an elliptical, circular or polygonal plane or part or combination thereof. It will be appreciated that such bilayer may be one of a plurality of substantially coplanar bilayers arranged in coaxial, concentric or equivalent manner.

Reference to a concentric spiral plane which is curved or angled is to a plane which is coiled or wound in on itself in a manner such that it forms a geometric body of which a cross section comprises a two-dimensional curved or angled spiral. Preferably curves and angles are continuous thereby minimising the pressure drop along the second fluid path length.

The bilayers of the invention are thereby adapted for the selection of first fluid path length with reference to the number of coplanar bilayers or of concentric spirals thereof, i.e. comprising a substantially constant number of first fluid path lengths per

bilayer or section, to obtain a desired cross sectional area of mixing or separating contact of first and second fluid within a desired first fluid pressure drop constraint.

Suitably therefore a bilayer which is one of a plurality of corresponding bilayers or which is in the form of a concentric spiral is adapted to provide for passage of one of a first and a second fluid enclosed within each separate bilayer or concentric portion thereof and isolated from the other of the first and second fluids which is adapted to pass between and contact the external surfaces of each of any two coplanar bilayers or concentric portions thereof, i.e. the plurality of corresponding bilayers or concentric portions thereof may be arranged in the first or second fluid flow path whereby the first or second fluid is able to pass therebetween, along the external corrugations thereof.

The bilayers of the invention are essentially scale independent, having regard to the ability to select the first fluid (and second fluid) path lengths thereof. For example a bilayer may have a total first fluid path length of 1cm to 5 metres or more and a total second fluid path length of 10cm to 50 metres or more, corresponding to a greatest geometric form dimension of 1cm to 10 metres or more.

It will be appreciated that the pressure drop constraint to which gaseous fluids are susceptible is more severe than that to which liquid fluids are susceptible, whereby physical constraints are substantially minimised by decreasing the gaseous fluid path length. It will also be appreciated that in the event that the pressure drop constraint of an apparatus in respect of both fluids is critical, it is preferred to employ a bilayer as hereinbefore defined which is formed into a part of a geometric form and is one of a plurality of corresponding end-to-end aligned bilayers defining a plane as hereinbefore described, i.e. whereby the end-to-end path length of each bilayer is less than the curved or angled planar length of contact of the first and second fluids. For example a circular cross-section bilayer may comprise 2, 3 or 4 bilayers in the form of arcs subtending angles of 180°C, 120°, 90° etc., as shown in Figure 3.

A bilayer as hereinbefore defined may be formed with respective ends of the first and/or second fluid path associated with first and/or second fluid supply and effluent manifolds. Suitably a bilayer which is one of a plurality of substantially coplanar bilayers is associated with each of a single supply and effluent manifold common to each of the coplanar bilayers. Additionally, a bilayer which is formed into a part of a geometric form and is aligned end-to-end with one or more bilayers comprising the remaining parts of the geometric form, may be associated with each of a single supply and effluent manifold in common with co-aligned bilayers, as shown in Figure 3. Arrangement of manifolds will however be determined with reference to ease of access and connection considerations and the like.

In a further aspect of the invention there is provided a process for the preparation of a bilayer as hereinbefore defined comprising the assembly of two polymer films as hereinbefore defined, and the sealing thereof. Preferably two films are moulded to obtain the desired corrugation and simultaneously or otherwise are sealed or bonded and are formed to obtain the desired configuration as hereinbefore defined, and are preferably simultaneously moulded to obtain the desired corrugation and geometric form. It will be appreciated that pre-corrugated film may be cut and formed as desired with minimal costs or that film may be corrugated and formed simultaneously with use of a dedicated template or die with associated higher product quality.

It is an advantage that a bilayer sheet may be formed into a 3 dimensional structure, such as a spiral or folded structure, whereby only two membranes need be bonded rather than multiple membranes in a matrix.

In a further aspect of the invention there is provided an apparatus comprising a bilayer as hereinbefore defined.

In a further aspect of the invention there is provided the use of an apparatus as hereinbefore defined comprising a bilayer a hereinbefore defined for mass flow or separation application wherein the first fluid is gas and the second fluid is liquid,

selected from fluids commonly employed in applications such as mechanical, biological, and chemical processes such as flue gas, engine, machinery, furnace or motor coolants, waste industrial and domestic appliance effluents, and fluids commonly employed for the recovery of recyclable material or fluids therefrom.

The invention is now illustrated in non-limiting manner with reference to the following Examples and Figures:

Example 1 – Preparation of corrugated membrane

A bilayer is made by bonding two corrugated strips of 200μm PEEK, PES, PTFE, PVDF or perfluoropolymer ion-exchange membrane, for example 10cm wide and 1m long at their periphery as shown in Figure 1. The corrugations are aligned at 45° to the strip length but cross at 90° in order to hold the strips apart. Thus a flow channel is created for the fluid which passes between the inlet/outlet ports provided at each end. The membrane bilayer is optionally configured as a spiral as shown in Figure 2.

Example 2 – Crossflow filtration of emulsions

Crossflow filtration experiments were carried out with various forms of membranes. For corrugated membranes, the direction of corrugated lines are at 90° vertical to the flow direction when placing in the membrane unit. To compare the effect of cross flow on flux rate, another similarly corrugated membrane whose corrugated lines are parallel to the flow direction, was placed on the surface of the first one in order manually to form crossflow. The experimental operation conditions are constant during all runs. Transmembrane pressure is 0.35 bar, and temperature kept at 45°C. Concentration of emulsion is 30 wt% (water/emulsion). The density of the emulsion is 0.858g/ml, determined by a density bottle. The density of filtrate is 0.7945g/ml, measured by a Westphal balance.

The results are shown in Table 1 and Figures 4 & 5.

Results

Table 1. Effect of Corrugated Membranes

Membrane	Shape	Crossflow (ml/s)	Flux*3 ($1/m^2h$)
PTFE*1	Flat	44.69	21.45
	Corrugated Single Layer	44.69	517.31
	Corrugated Double Layer	44.69	603.40
	Corrugated Double Layer	7.47	129.89
PVDF*2	Flat	95.43	6.25
	Corrugated Single Layer	95.43	25.43

*1 PTFE is from Mupore with pore size of 3μm

*2 PVDF is from Schleicher & Schuell with pore size of 0.2μm

*3 Flux is obtained at the beginning of filtration

Discussion

The corrugated PTFE and PVDF show a significant effect on flux enhancement which is shown in Table 1. The corrugated PTFE from Mupore with a pore size of 3μm gives extremely high flux rate, which is almost 30 times larger than the flat PTFE, (Figure 4). However, the retentate rate of emulsion is poor due to pore size being much larger than emulsion droplet size (average 0.2μm). A large amount of emulsion droplets permeating through the membrane also results in a sharp flux decline as Figure 5 shows.

Therefore it is suggested that a membrane with pore size smaller than a filtration medium may give better flux performance with a high separation rate.

Following this reasoning, corrugated PVDF with pore size of 0.2μm was used instead. A relative constant flux curve was obtained as shown in Figure 5.

Example 3 Effects of membrane corrugations

The typical influence of membrane corrugations on filtration performance is shown in Figure 6. The flux rates are based on the projected area of membrane in order to observe the combined effect of turbulence promotion and surface area enhancement. The influence of corrugations is markedly greater at higher feed flow velocities. As expected, increases in the angle of cross-corrugation result in increases in flux rates. The greatest flux improvement is accomplished at an angle of 90°, simply because the highest level of turbulence promotion is reached at this angle. Flux increases of about 30, 100 and 160% in comparison with flat membranes can be achieved for parallel, 45° and 90° angles of cross-corrugation, respectively. On the other hand, and as expected, parallel corrugations show no improvement in flux rates (based on real area of membrane) in comparison with flat membranes. As Figure 6 suggests, the flux is markedly improved in the presence of membrane corrugations. The improvement is much more prominent at higher feed flow velocities.

The increase in flux is thought to be caused by two factors, surface area enhancement and turbulence promotions induced by corrugations. The surface area of the corrugated membranes was approximately 21cm^2. This corresponds to about 30% of area enhancement in comparison with flat membranes (area of about 16cm^2). This suggests that at least 30% improvement in flux should be expected for corrugated membranes, regardless of the angle of cross-corrugation used.

The effect of the other factor, turbulence promotion, appears to be much more predominant than enhancement of area. The mechanism of corrugations as turbulence promoters can be explained as follows. The flow of feed along the membrane corrugations results in a scouring action, which repeatedly disrupts and promotes mixing of the boundary layer formed at the membrane surface through

formation of fluid eddies. This leaves insufficient length of channel through which the feed can flow undisturbed. Therefore, this effect causes an increase in the permeate flux due to the combined effect of thinning the boundary layer and higher mechanical shear at the wall. The mixing and turbulence promotions produced by corrugations are thought only to occur near the membrane surface region.

Example 4 Effect of pressure drop and energy savings

Figure 7 shows the variation in pressure drop across a membrane module unit with the feed flow velocity for flat and corrugated membranes. For flat membranes, an increase in cross-flow velocity from 0.66 to 3.22m/s corresponds to an increase in pressure drop by about 0.5bar. This conforms with a flux enhancement from 5 to 20l/m^2/h. This increase in flux does not, however, outweigh the extra energy consumption entailed.

Figure 7 indicates that corrugated membranes (except for parallel corrugations) incur higher pressure drops than flat membranes. This is because turbulence promotion caused by corrugations introduces an additional resistance to axial flow and hence an increased friction and pressure drop. As the corrugations produce more turbulence, a higher angle of corrugations would be expected to incur a greater pressure drop. In comparison with flat membranes, the highest increase in pressure drop is, thus, obtained at a cross-corrugation angle of 90°, while parallel corrugations cause relatively negligible pressure drop increase.

It can, however, easily be demonstrated that the extra energy requirement entailed by higher pressure drops can be greatly outweighed by flux rate enhancement. It can also be shown that corrugations do, in fact, result in great energy savings as clearly illustrated in Figure 8. The data in Figure 8 are obtained on the following basis. The cross-flow velocity which is required for corrugated membranes and would give the same flux rate (based on real area) as for flat membranes operated at a particular cross-flow velocity is determined. The corresponding pressure drops for flat and

corrugated membranes are found from Figure 7. The pumping power ratios for flat and corrugated membranes are then calculated. The comparison has been based on the corrugated membranes having the same area as flat membranes (i.e. flux rates based on real area are used). This is to find the absolute cost saving achieved by using corrugated membranes.

It is apparent that significant pumping cost savings can be achieved with corrugated membranes. It can also be observed that there exists a particular cross-flow velocity corresponding to a maximum energy saving. At this point, the resistance to permeate flow is thought to reach its critical value which will remain unchanged with further increase of the velocity. Energy savings of up to about 88 and 80% (corresponding to pumping power ratios of 0.13 and 0.18) are achieved with 90° and 45° corrugations, respectively, at a cross-flow velocity of 2.5m/s. Membranes with parallel corrugations, on the other hand, provide no saving in pumping power. Figure 8 clearly illustrates the variation of energy efficiency with the flux rate indicating that maximum energy savings (88 and 80%) are achieved at a flux rate of $17.5 l/m^2/h$.

Further advantages of the invention are apparent from the foregoing.

CLAIMS:

1. A porous bilayer element arranged such as to form respective flow paths for first and second gaseous or liquid fluids, which fluids may be the same or different, wherein the bilayer is adapted for turbulent flow of at least one of the first and second fluids.

2. An element as claimed in claim 1, wherein the element is porous to at least one component of at least one of the first and second fluids, which component may comprise or be contained within the fluid.

3. An element as claimed in claim 1 or 2, wherein the element is a membrane element.

4. An element as claimed in claim 3, wherein a ratio of a surface area of the membrane adapted to contact both fluids to a total matrix volume is in excess of $700m^2/m^3$.

5. An element as claimed in claim 3 or 4, wherein each membrane of the bilayer provides fluid flow channels for one of the first and second fluids and provides turbulence generating features for the other of the first and second fluids.

6. An element as claimed in claim 5, wherein the flow channels for one of the fluids provide on a reverse side thereof the turbulence generating features for the other fluid.

7. An element as claimed in any one of claims 3 to 6, wherein the bilayer membrane comprises two corrugated membranes.

8. An element as claimed in claim 7, wherein the two membranes are disposed such that their corrugations are crossed with respect to each other.

9. An element as claimed in claim 8, wherein the two membranes are disposed with a cross-corrugation angle of 25° to 90°.

10. An element as claimed in claim 9 depending ultimately from claim 5, wherein the fluid flow channels are disposed in a substantially flat plane and wherein the cross-corrugation angle is from 60° to 90°.

11. An element as claimed in claim 9 depending ultimately from claim 5, wherein the fluid flow channels are disposed in a substantially curved or angled plane and wherein the cross-corrugation angle is from 25° to 60°.

12. An element as claimed in any one of claims 3 to 11, wherein the membranes have a pore size from 0.01 to 500μm.

13. An element as claimed in any one of claims 3 to 12, wherein the membranes are made of the same material.

14. An element as claimed in any one of claims 3 to 12, wherein the membranes are made of different materials.

15. An element as claimed in any one of claims 3 to 14, wherein at least one of the membranes is made out metal.

16. An element as claimed in any one of claims 3 to 15, wherein at least one of the membranes is made out of a polymer material.

17. An element as claimed in any one of claims 3 to 16, wherein at least one of the membranes is made out of a ceramic material.

18. An element as claimed in any one of claims 3 to 17. wherein at least one of the membranes is made out of glass.

19. An element as claimed in any one of claims 3 to 18. wherein at least one of the membranes is made of a composite material.

20. An element as claimed in claim 15, wherein the metal membrane is configured as an electrode.

21. An element as claimed in any one of claims 1 to 10 and any one of claims 12 to 20 depending ultimately from claims 1 to 10, wherein the element is substantially in the form of a flat lamina.

22. An element as claimed in any one of claims 1 to 9 and any one of claims 11 to 20 depending ultimately from claims 1 to 9, wherein the element is substantially in the form of a curved or angled lamina.

23. An element as claimed in claim 22, wherein the element is wound onto itself in a spiral manner.

24. An apparatus comprising a plurality of elements as claimed in any one of claims 1 to 23, the elements being stacked or otherwise mutually disposed so as to create respective flow paths for a first and a second fluid.

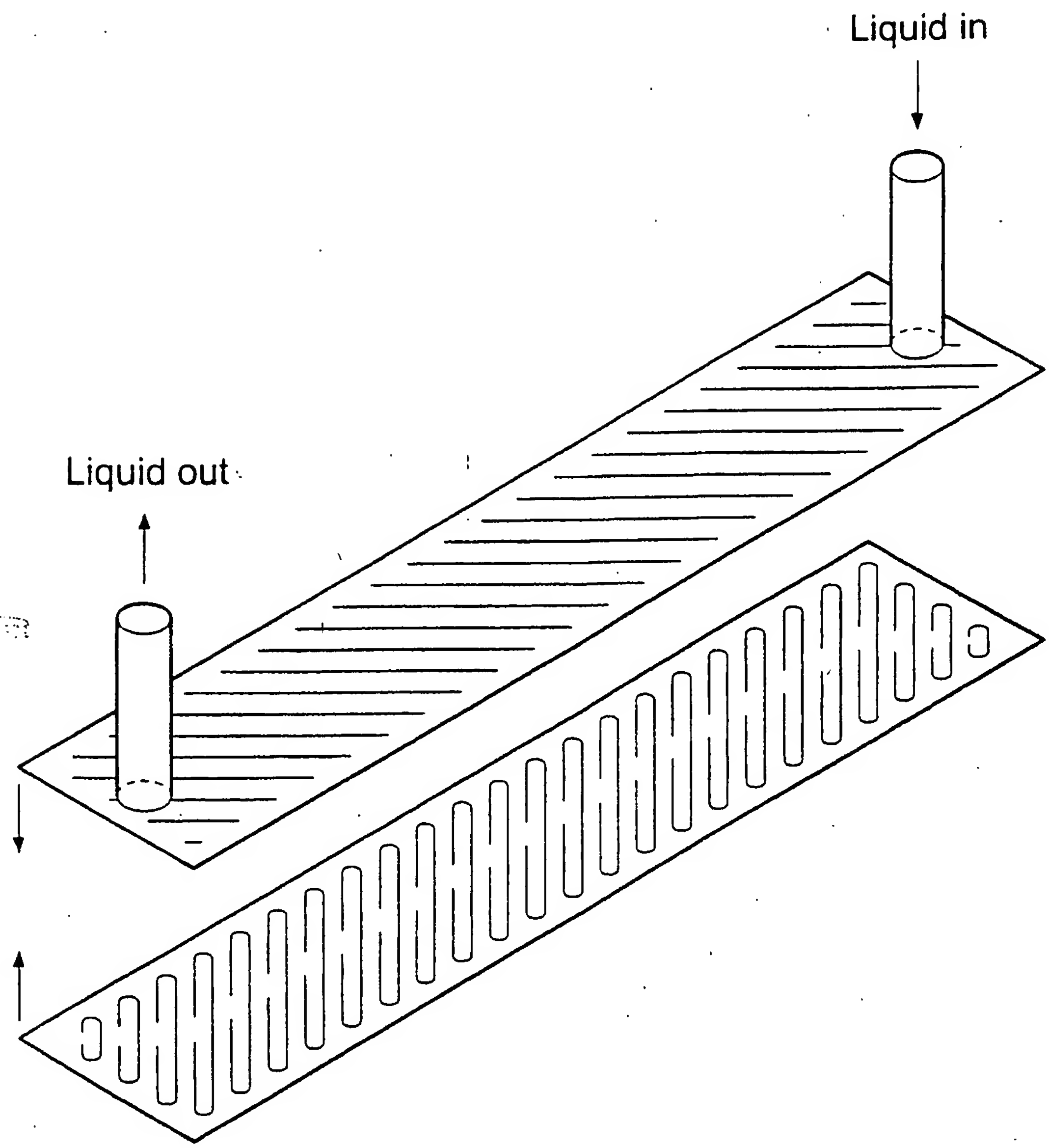


Fig. 1

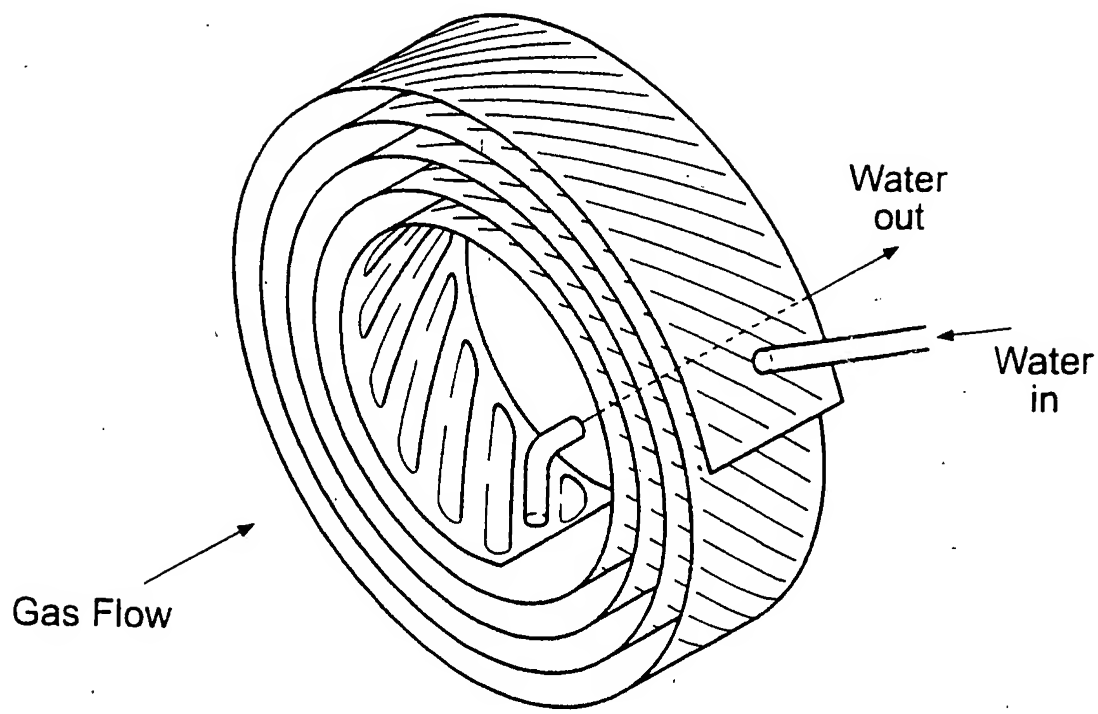


Fig. 2

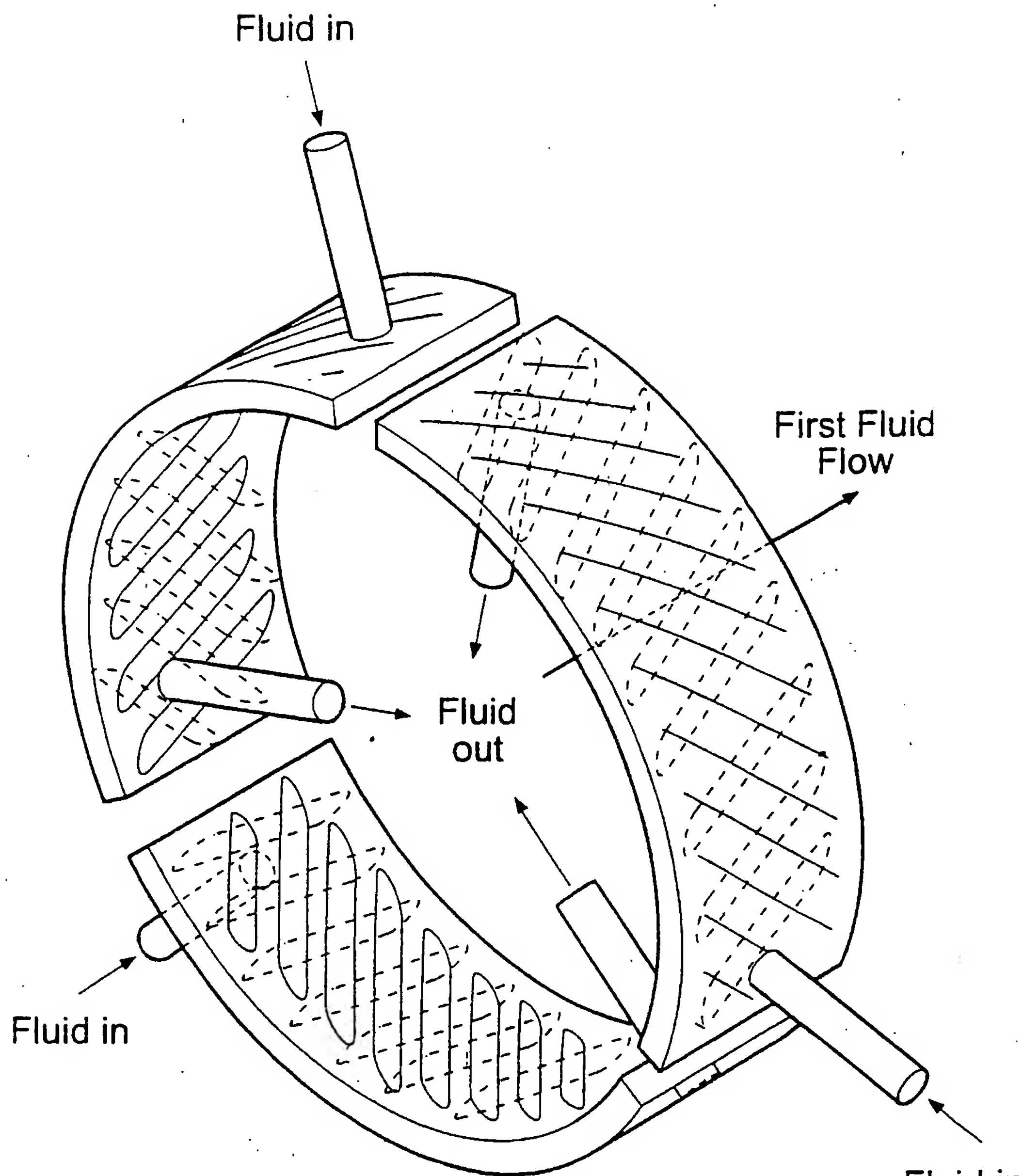
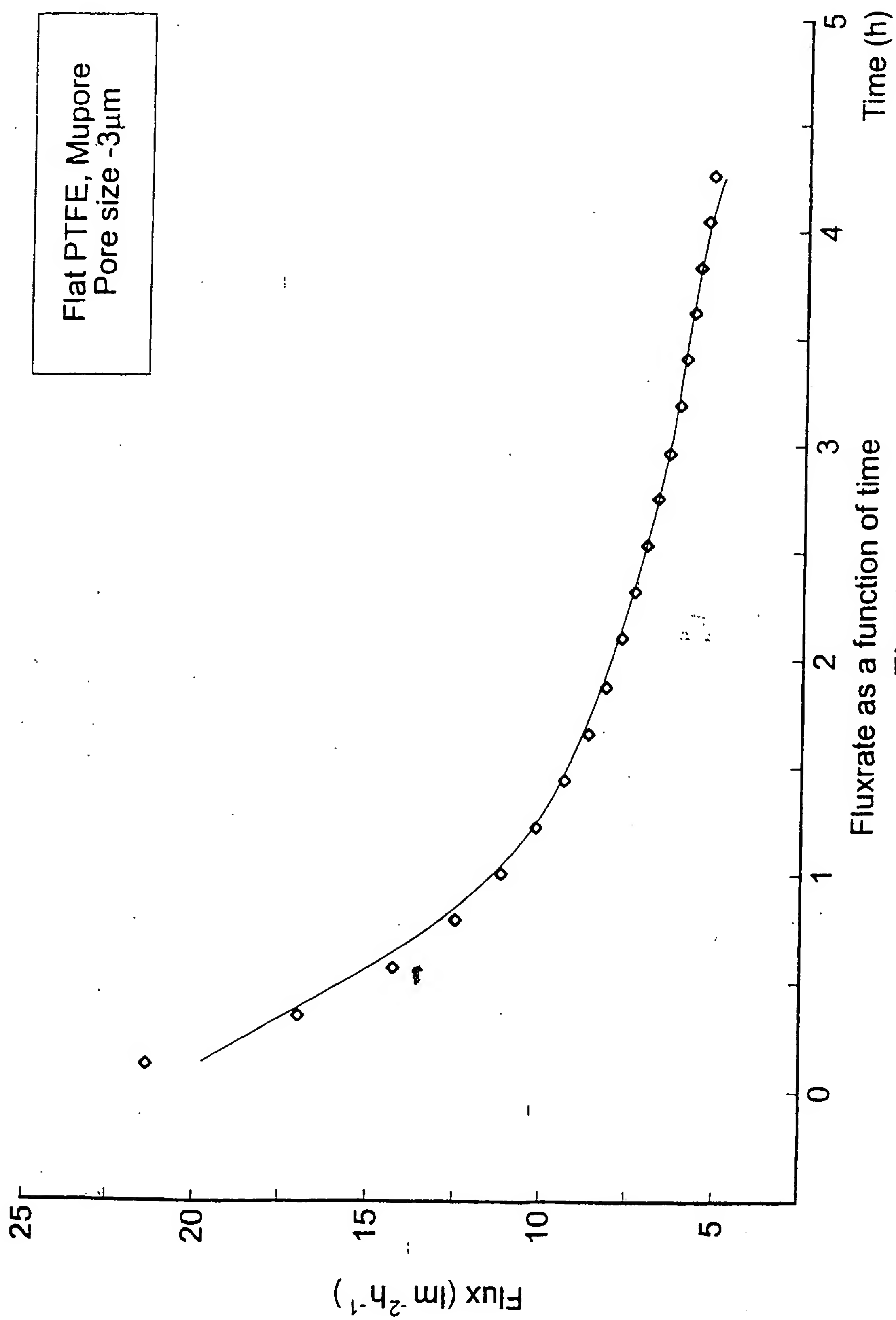
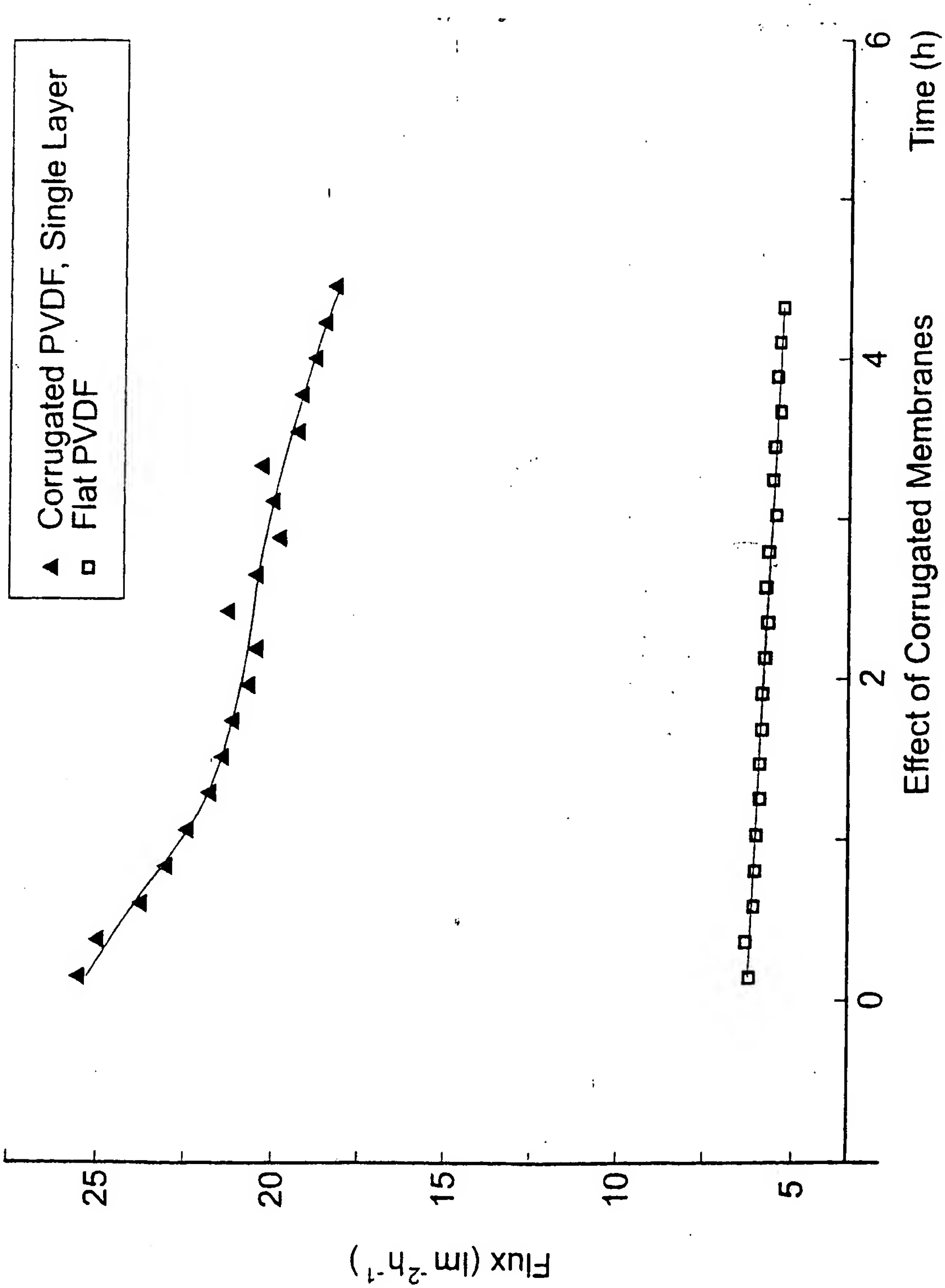


Fig. 3



Fluxrate as a function of time

Fig. 4



Corrugated PVDF, Single Layer
Flat PVDF
Flux (lm⁻²h⁻¹)
25
20
15
10
5
0
2
4
6
Time (h)
Effect of Corrugated Membranes

Fig. 5

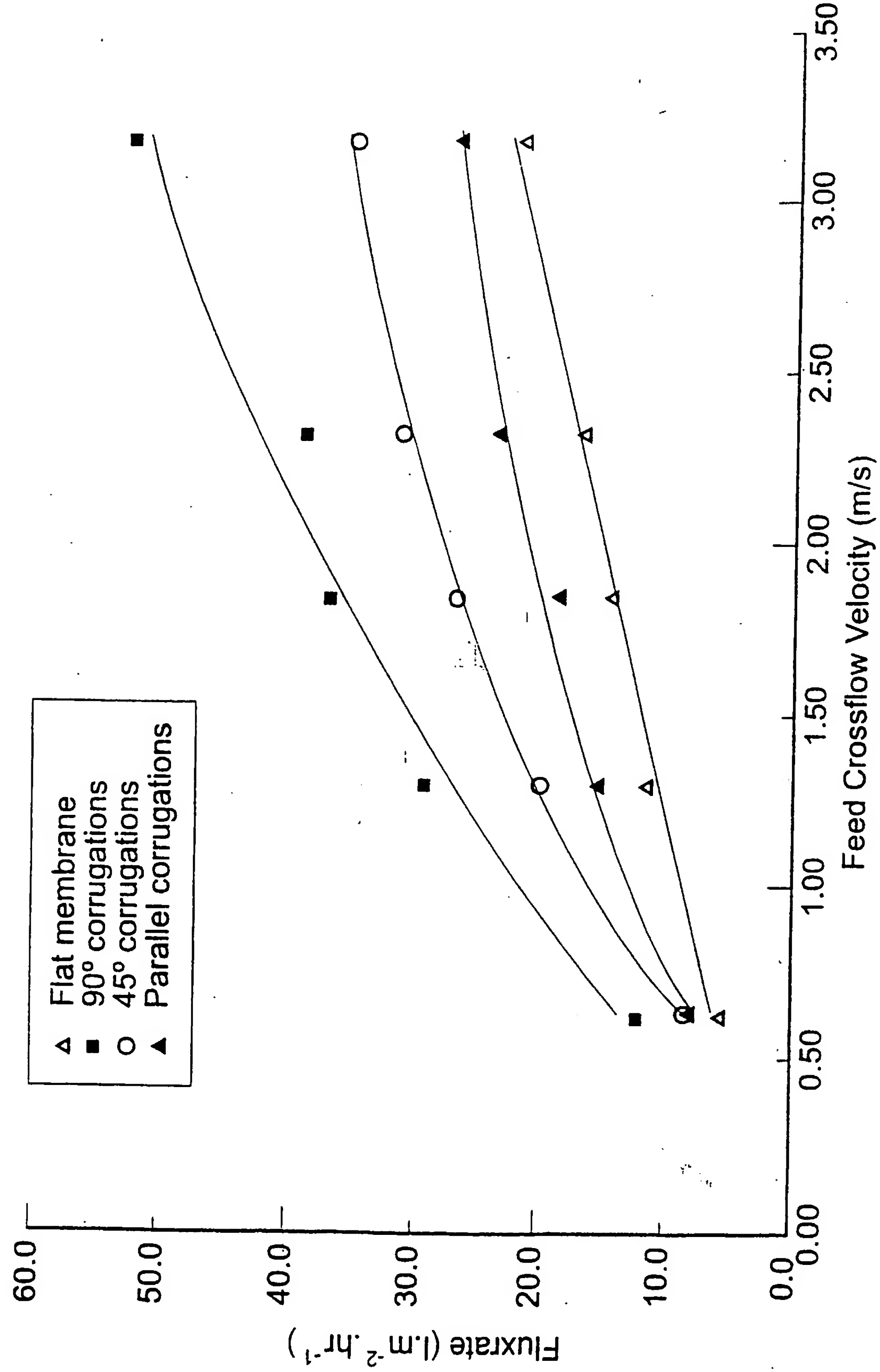
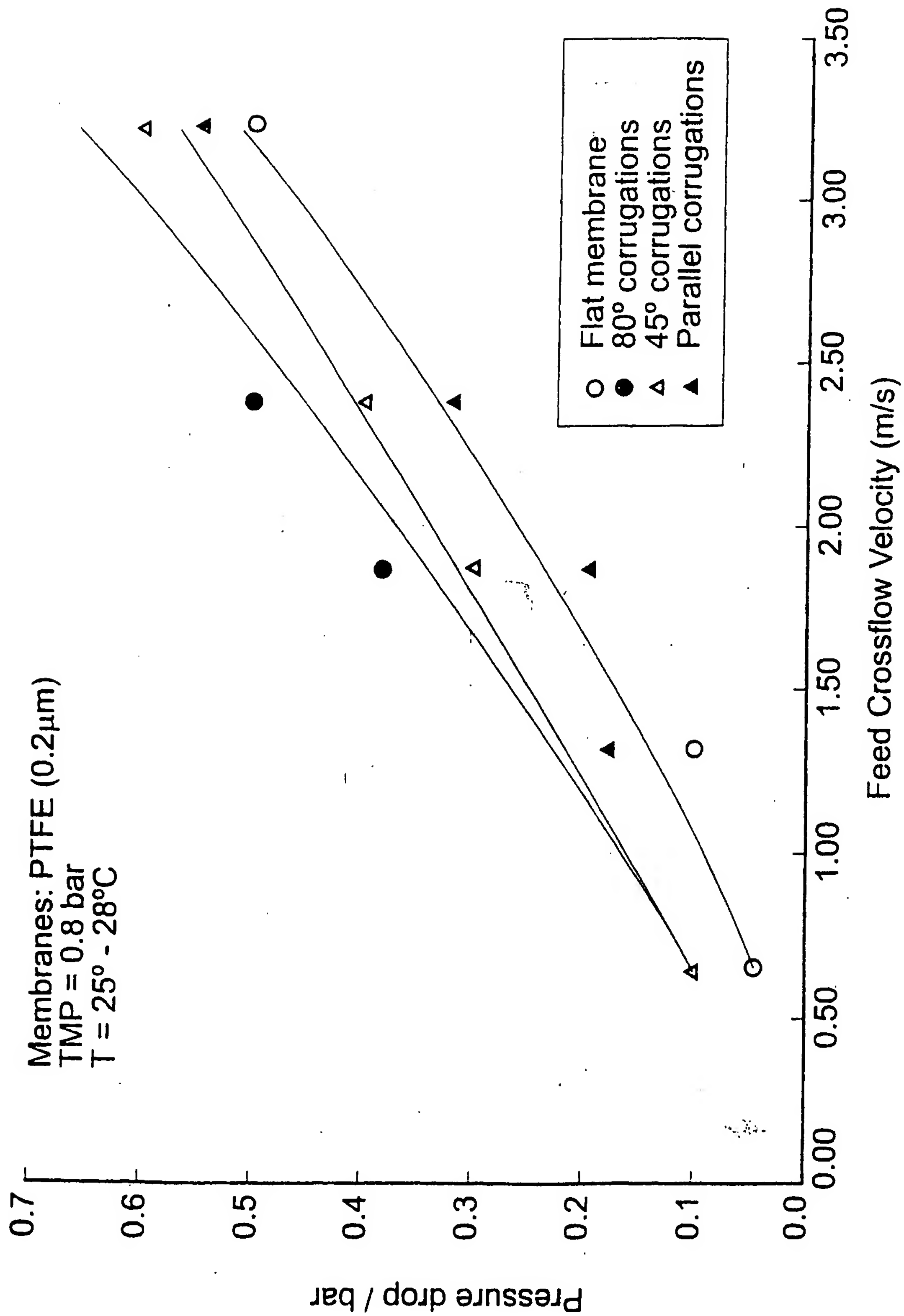

Flux rate (l.m^{-2}.hr^{-1})
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
Feed Crossflow Velocity (m/s)
Flat membrane
90° corrugations
45° corrugations
Parallel corrugations

Fig. 6



Variation of pressure drop with CFV

Fig. 7

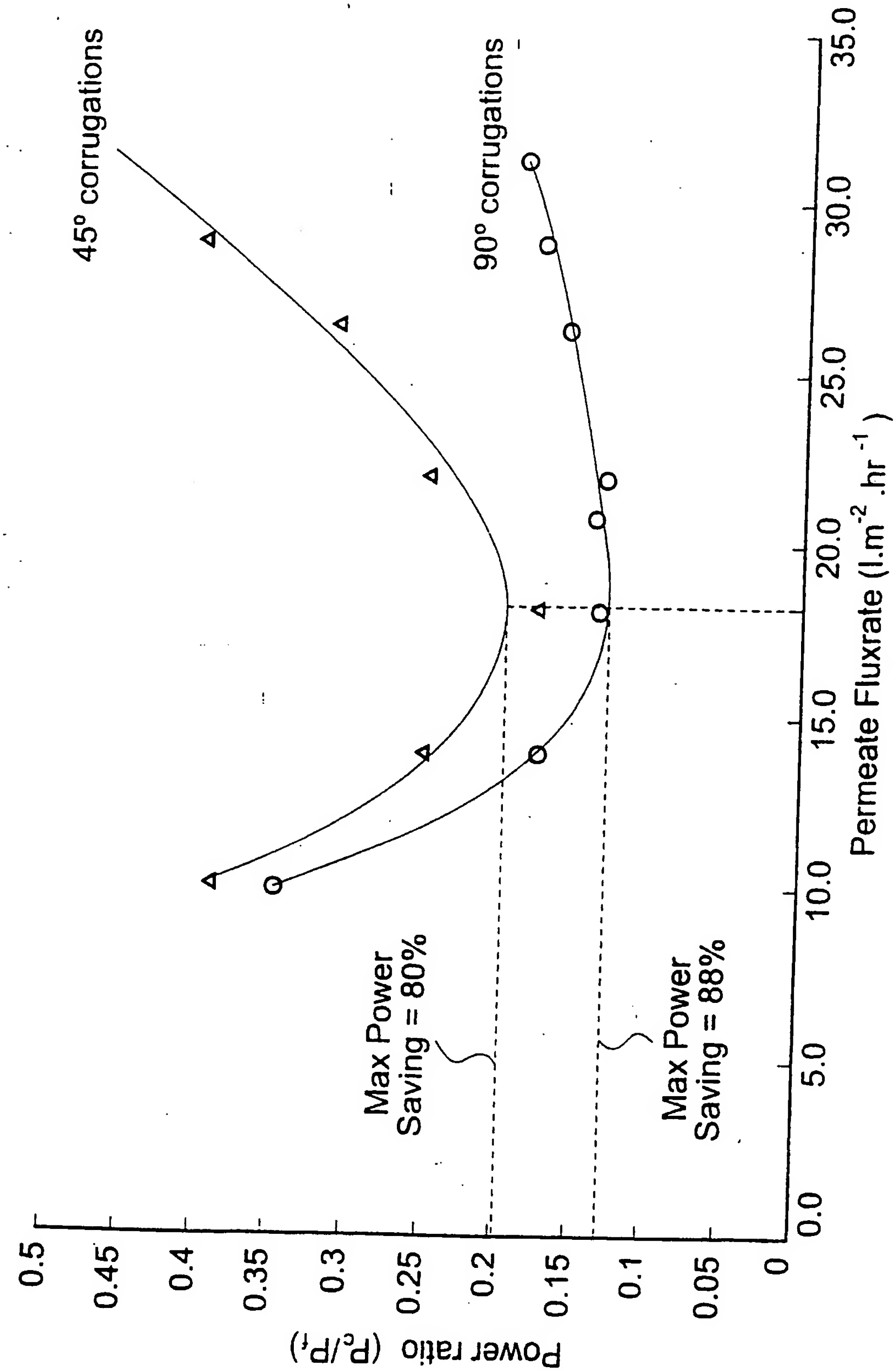

45° corrugations
90° corrugations
Max Power Saving = 80%
Max Power Saving = 88%
Power ratio (Pc/Pf)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
Permeate Fluxrate (l.m-2.hr-1)

Fig. 8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/03884

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B01D63/08 B01D63/10 B01D65/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 230 403 A (DU PONT) 20 December 1974 (1974-12-20) claims; figures 20-35 page 1, line 29 -page 2, line 40 page 15, line 19 -page 17, line 13 page 19, line 1 - line 18 page 22, line 19 - line 22 page 24, line 14 - line 22 ---	1-3, 5-11,13, 16,21-24
X	US 4 451 370 A (MURAI MASATAKA ET AL) 29 May 1984 (1984-05-29) the whole document ---	1-3, 5-13,16, 19,21,24

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 December 2000	15/12/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hoornaert, P

INTERNATIONAL SEARCH REPORT

International Application No
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/03884

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	GB 2 236 693 A (FOSECO INT) 17 April 1991 (1991-04-17) cited in the application the whole document	1-3,5-7, 12,17, 21,24

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Information on patent family members

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